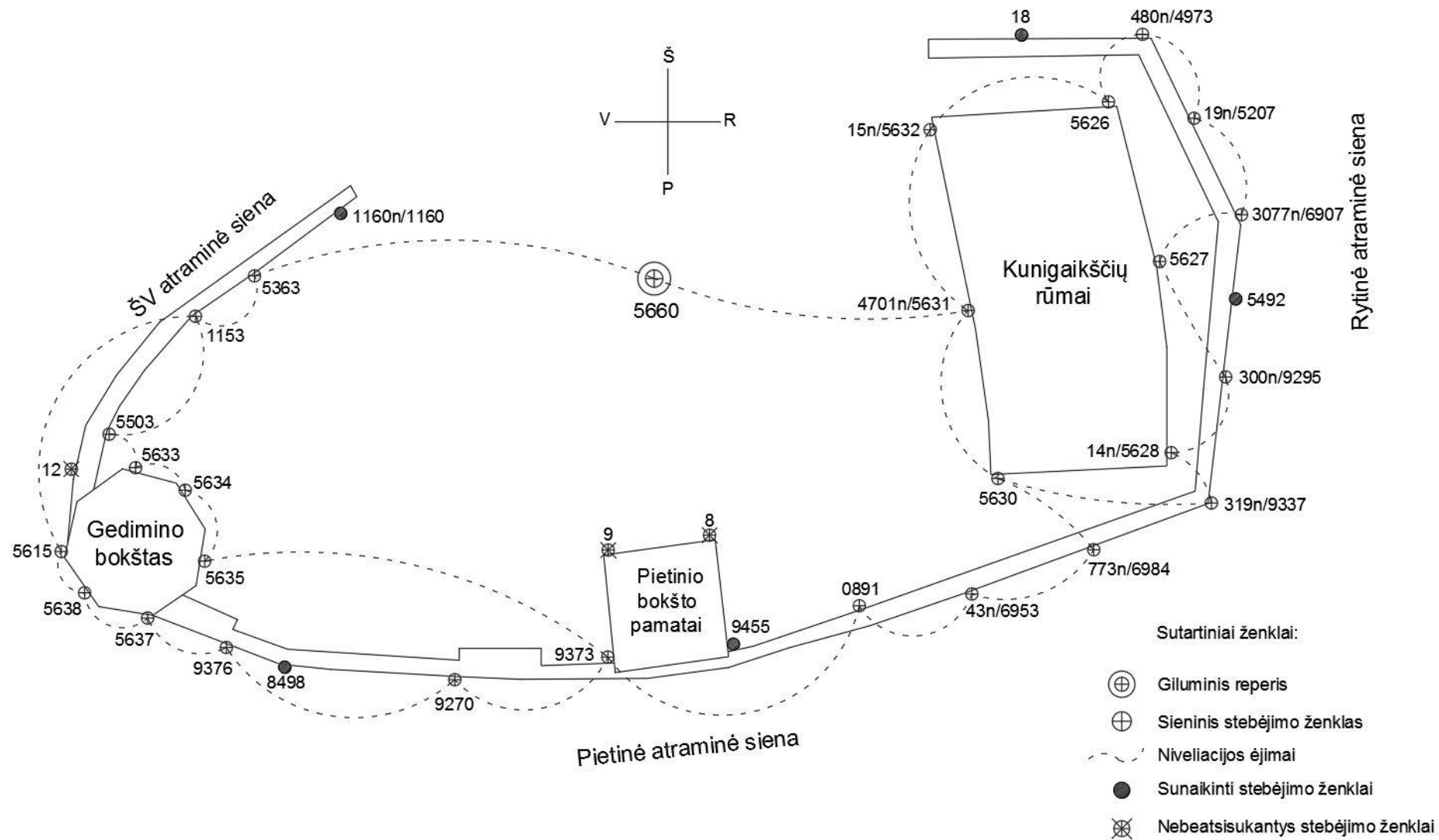
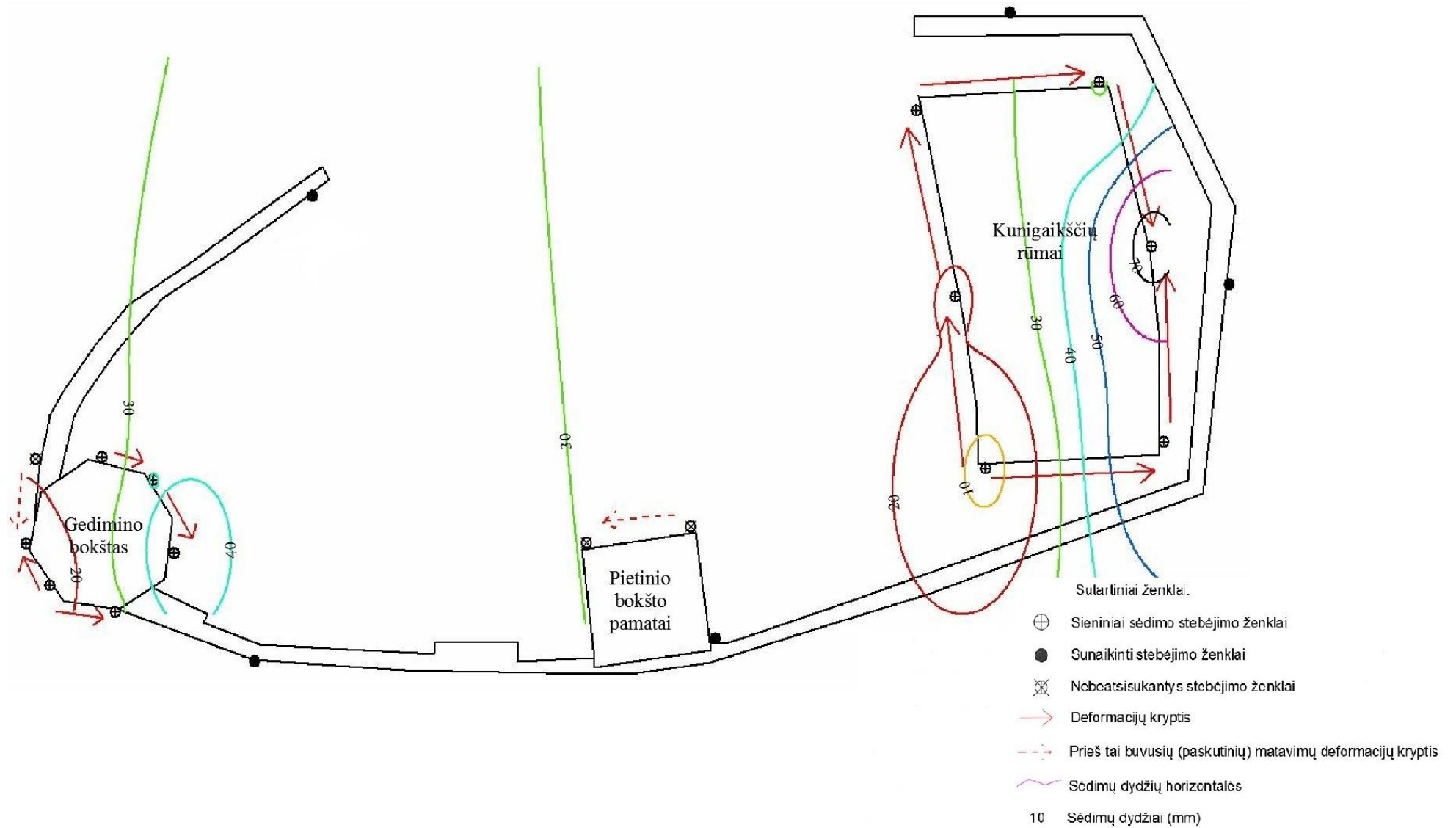


PRIEDAI

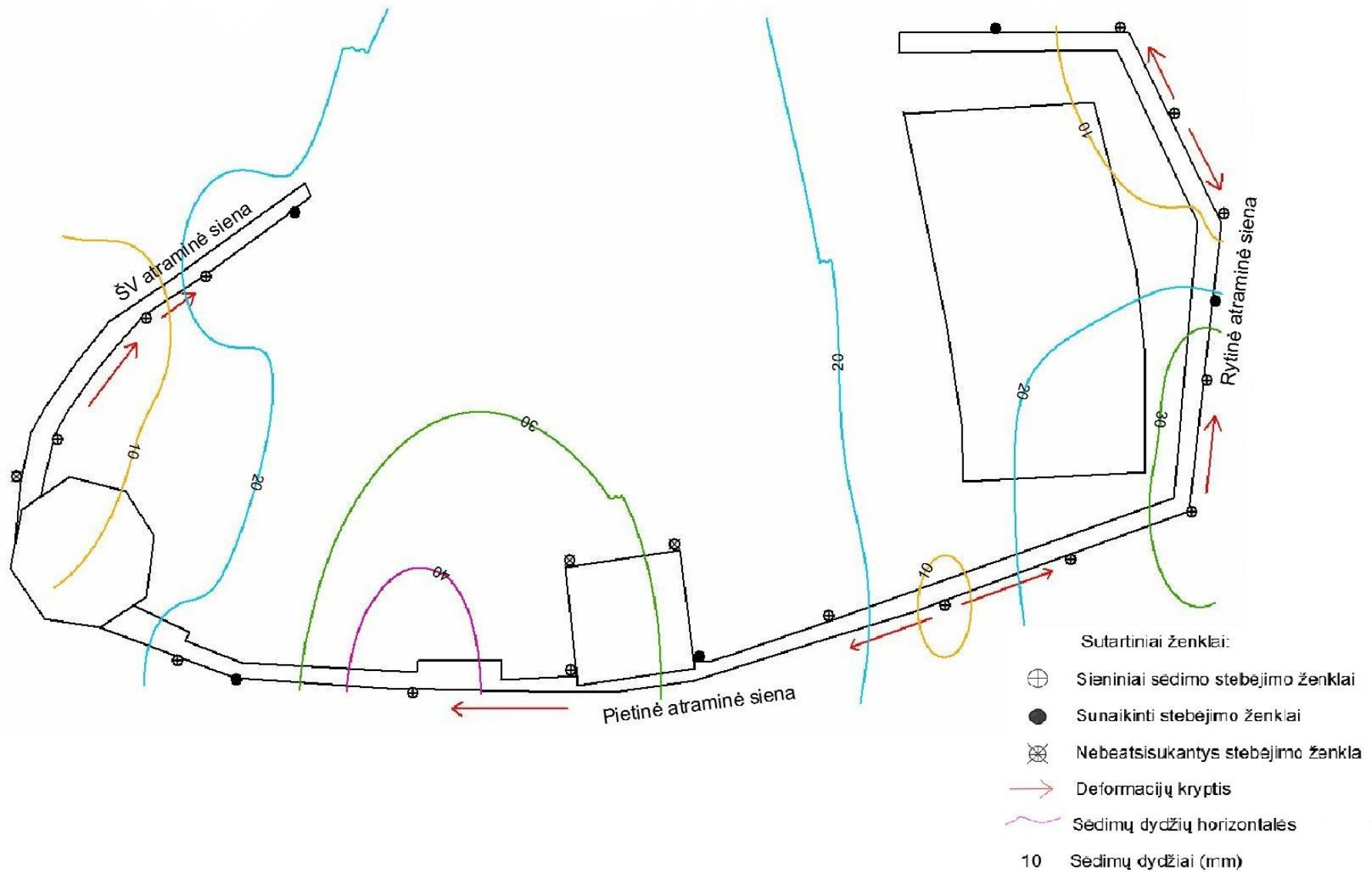
A PRIEDAS. 2016 m. balandžio 6 d. sėdimo markių išdėstymo ir niveliavimo schema



B PRIEDAS. 2016 m. balandžio 6 d. sėdimo markių, įtvirtintų nuo 1968 m. lapkričio mėn., išdėstymo ir matavimo rezultatų schema



C PRIEDAS. 2016 m. balandžio 6 d. sėdimo markių, įtvirtintų nuo 1995 m. gruodžio mėn., išdėstymo ir matavimo rezultatų schema



D PRIEDAS. Straipsnis 19-oje Lietuvos jaunųjų mokslininkų konferencijoje „Mokslas – Lietuvos ateitis“



2016 m. kovo 25 d. Vilnius

25 March, Vilnius, Lithuania

VILNIAUS AUKŠTUTINĖS PILIES VERTIKALIŲ DEFORMACIJŲ TYRIMAI

Greta Miltinytė¹, Vladislovas Česlovas Aksamitauskas²

¹magistrantė, ²profesorius

Vilniaus Gedimino technikos universitetas,

el. p. ¹greta.miltinyte@stud.vgtu.lt; ²ceslovas.aksamitauskas@vgtu.lt

Anotacija. Darbe apžvelgtas tyrimo objektas, jo vertikalųjų deformacijų stebėjimo metodika, statinių deformacijų atsiradimo priežastys. Surinkti ir susisteminti duomenys apdoroti matematiniais – statistiniais metodais. Atlikta visų matavimų ciklų apžvalga ir pateiktos jų išvados. Siekiant ištirti statinių būklę, duomenys pateikiami grafiškai. Analizuojant grafikus, ištirti statinių pokyčiai ir pateiktos galimos jų atsiradimo priežastys. Norint ištirti klimato įtaką sėdimų dydžiams, panaudoti hidrometeorologiniai duomenys iš Lietuvos hidrometeorologijos tarnybos prie Aplinkos ministerijos.

Reikšminiai žodžiai: Vilniaus Aukštutinė Pilis, Gedimino bokštas, Kunigaikščių rūmai, statinių deformacijos, vertikaliosios deformacijos, sėdimai, ciklas.

Įvadas

Deformacijos gali būti vertikalinės (sėdimai) bei gruntų poslinkis horizontalioje padėtyje (nuošliaužos). Dažniausios statinių sėdimo priežastys: nevienoda statinio pagrindo geologinė struktūra; grunto iškilimas prieš įrengiant pamatus; grunto pakilimas (pūtimasis) dėl šalčio įtakos; drėgmės ir grunto atšilimas; statinių svoris; slėgio pasikeitimas į gruntą pasikeitus statinio svoriui; netolygus slėgio pasiskirstymas priklausomai nuo statinio svorio po pamatais; pamatų matmenys; kietumas ir forma; dinaminės apkrovos į pagrindus; grunto stiprumo pokytis atliekant požeminę statybą; žmogaus įtaka; dirbantys mechanizmai ir kt. Jeigu sėdimai yra dideli ir netolygūs tuomet gali atsirasti įvairūs plyšiai ir įtrūkimai. Norint stebėti statinių pokyčius, yra atliekami stebėjimai – matavimai. Stebėjimai gali būti fizikiniai ir geodeziniai (Ražinskas 1979).

Vilniaus miesto Aukštutinė pilis yra svarbus respublikinės reikšmės XVI – XIX a. architektūros, istorijos ir archeologijos paminklas, todėl ją būtina išsaugoti ateities kartoms. Dėl to dar nuo 1968 m. buvo

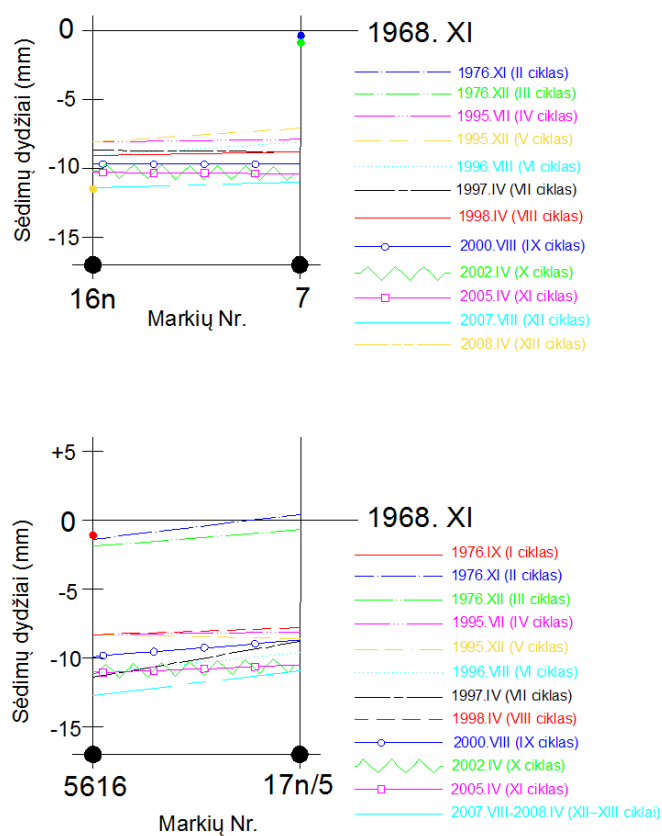
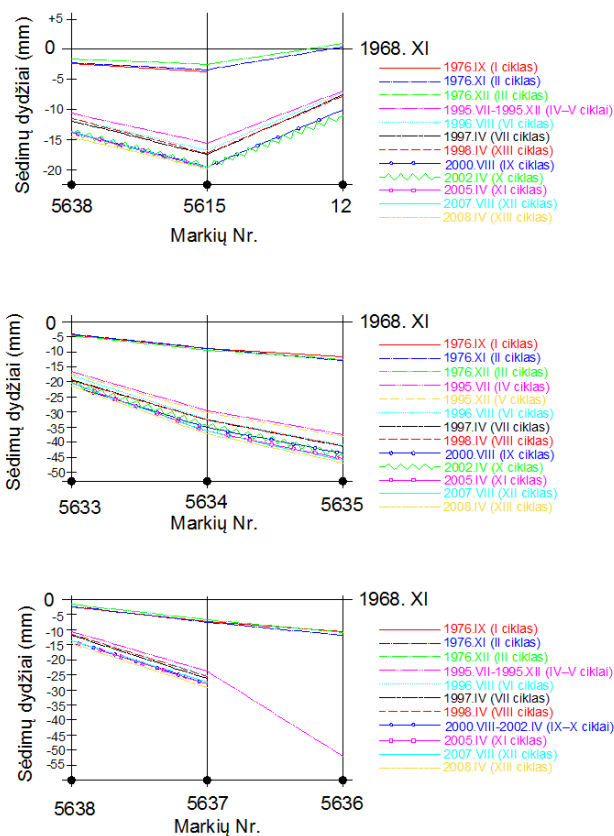
imta stebėti kalno ir statinių deformacijas, kad būtų galima sekti pilies būklę, prognozuoti jos deformacijas.

Darbo tikslas – atlikti Vilniaus Aukštutinės pilies vertikalųjų deformacijų tyrimus.

Tyrimų metodika – dugjamečių matavimų duomenų surinkimas ir susistemimas. Atliekamas jų tyrimas siekiant išsiaiškinti statiniuose vykstančius pokyčius. Sėdimų priežasčių išaiškinimas bei padarytų išvadų realumo vietovėje patikrinimas.

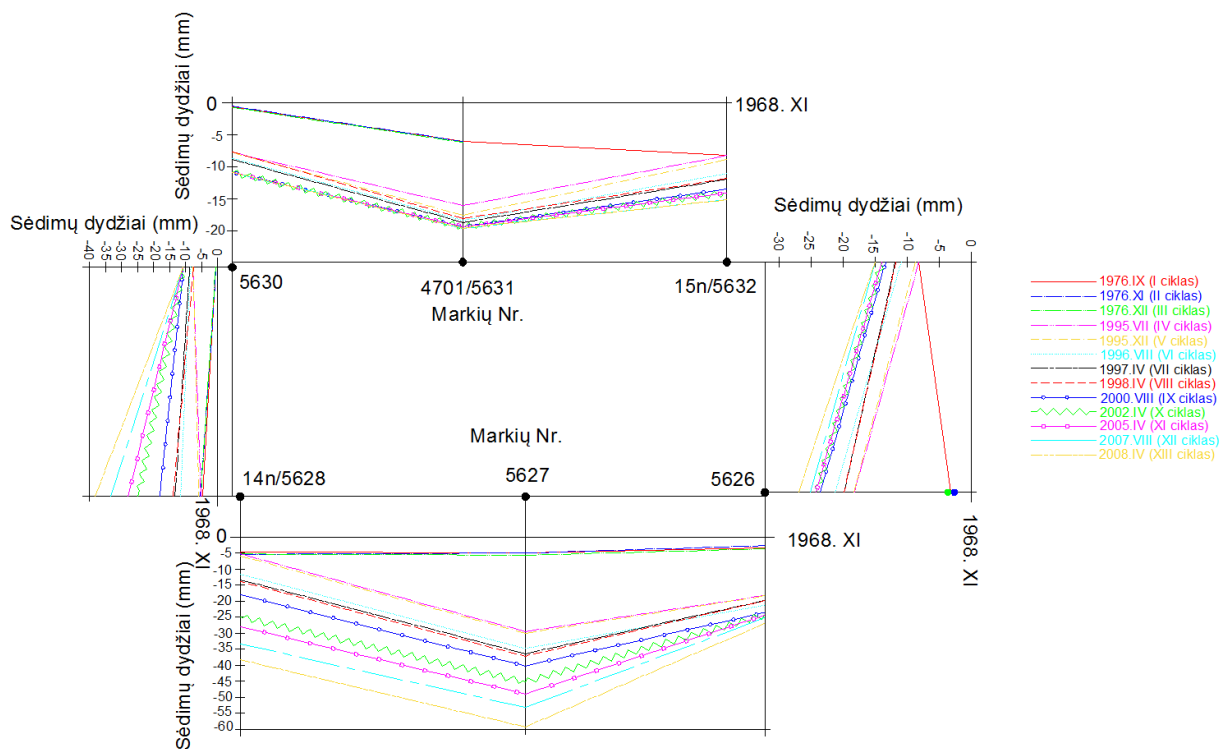
Tyrimui atlikti, naudojami duomenys yra paimti iš daugiamečių techninių ataskaitų, kurios buvo ruošiamos kiekvieno matavimų ciklo metu. Pirmieji darbai buvo atlikti 1968 m. lapkritį, o paskutinis matavimų ciklas įvykdytas 2008 m. balandį. Iš viso per šį laikotarpį (40 metų) buvo atlikti XIII matavimų ciklų. Darbus vykdė UAB „Inžineriniai tyrinėjimai“. Darbų užsakovas – VĮ „Vilniaus pilių direkcija“. Darbų metu buvo stebimos Gedimino kalno ir jo statinių planinės bei vertikaliosios deformacijos. Šiame darbe pasirinkta nagrinėti Aukštutinės Pilies statinių vertikaliasias deformacijas.

3 pav. Rytinės atraminės sienos vertikalinės deformacijos

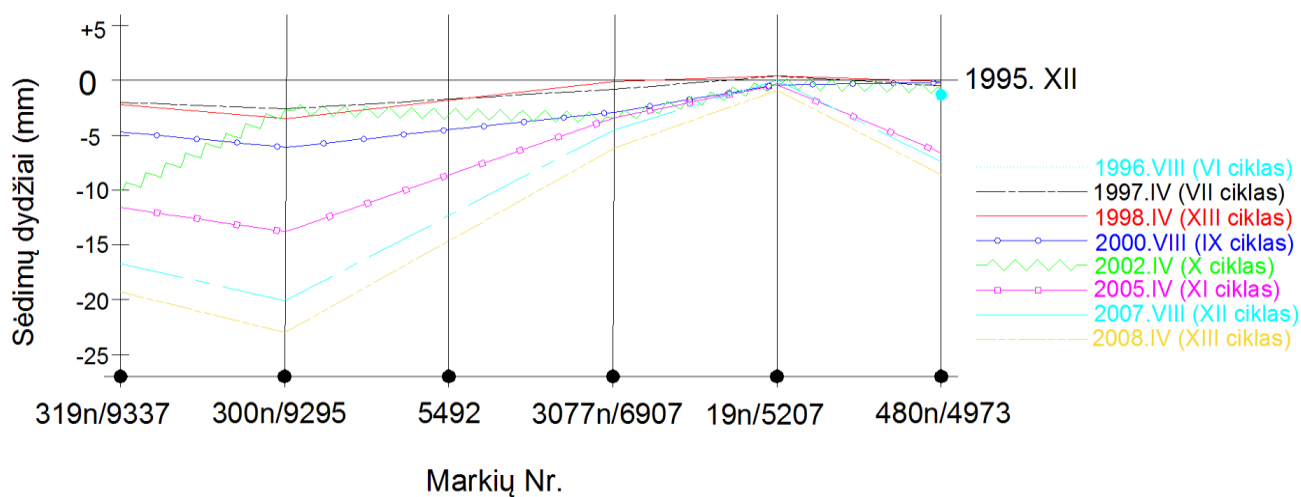


4 pav. Gedimino bokšto ir PV gynybinės sienos dalies vertikalinės deformacijos

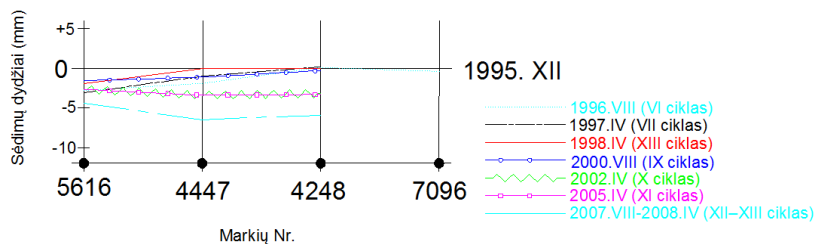
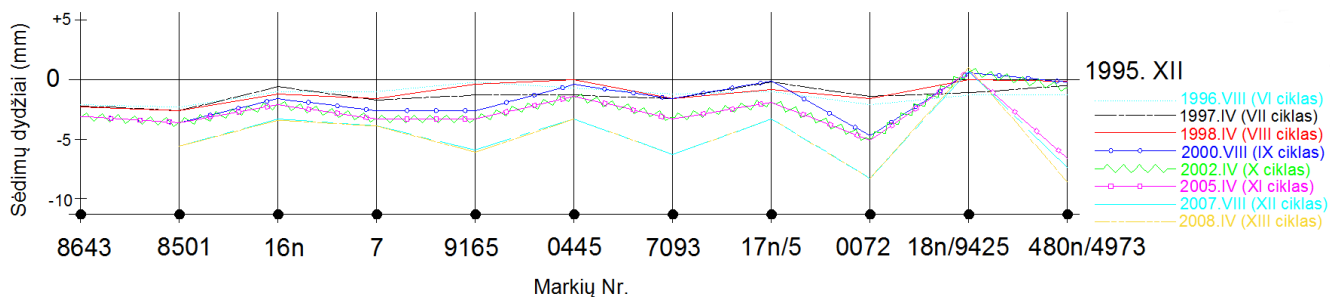
5 pav. Šiaurinės sienos (nuo 1968 m.) vertikalinės deformacijos



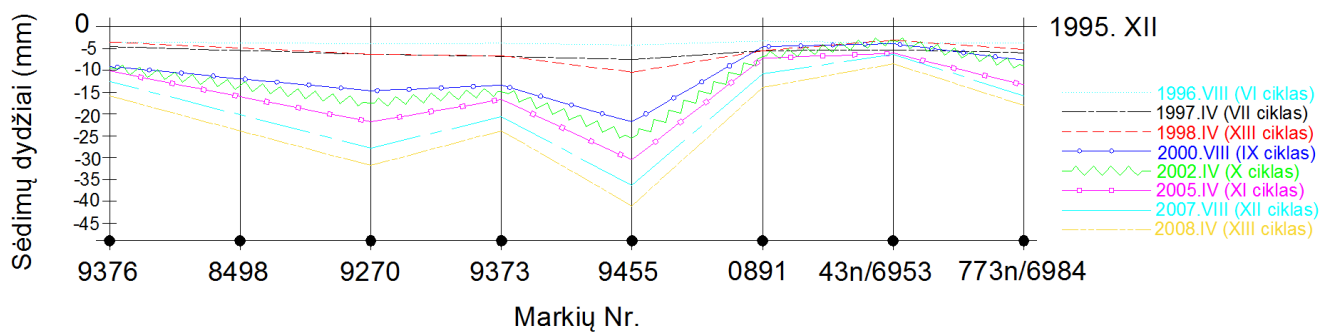
6 pav. Kunigaikščių rūmų vertikalinės deformacijos



7 pav. Pietinės atraminės sienos vertikalinės deformacijos



8 pav. Šiaurinės sienos (nuo 1995 m.) vertikalinės deformacijos



9 pav. Pietinės atraminės sienos vertikaliosios deformacijos

Apžiūrėjus vietovę buvo rastos išlikusios 36 markės. Viena iš jų, esanti ant Gedimino Pilies pavaizduota 10 pav. Statinių sienose matomi plyšiai tik patvirtina jog vyksta statinių deformacijos (10 pav.).



10 pav. Kairėje markė Nr. 5634; dešinėje Kunigaikščių rūmuose esantis plyšys

Išvados

1. Daugiamečiai (1968 – 2008 m.) Aukštutinės Pilies statinių tyrimų rezultatai parodė, kad ant kalno esantys statiniai, stebėjimo laikotarpiu, deformavosi (vyko sėdimai ir sienų trūkimai).

2. Galima teigti, kad didžiausi sėdimai stebimi pietiniuose statiniuose. 1968 m. lapkričio mėn. atžvilgiu (per 40 metų) vidutiniškai daugiausiai iš statinių sėdo Pietinio bokšto pamatai (46,7 mm); 1995 m. gruodžio mėn. atžvilgiu (per 13 metų) – Pietinė atraminė siena (21,8 mm). Mažiausi sėdimai užfiksuoti šiauriniuose statiniuose. 1968 m. lapkričio mėn. atžvilgiu (per 40 metų) vidutiniškai mažiausiai iš statinių sėdo Šiaurinė siena (11,7 mm); 1995 m. gruodžio mėn. atžvilgiu (per 13 metų) – taip pat Šiaurinė siena (5,1 mm).

3. Sėdimų reikšmės priklauso nuo daugelių faktorių: geologinių, hidrogeologinių, hirdrometeorologinių vietovės sąlygų, žmogaus ūkinės veiklos, statinių konstrukcinio stabilumo. Statūs šlaitai, augalai, palikti pūvantys kelmai, visa tai skatina šlaitų eroziją ir nuošliaužas. Šiems procesams didelę įtaką turi ir bloga nuotekų kanalizacija, pėsčiųjų ir krovinių keltuvo keliamos vibracijos, netinkamai atlikti šlaitų stabilizavimo darbai, Valdovų Rūmų atstatymo darbai, kalno lankytojų ištrypti augalijos plotai, „palaidoti“ požeminiai statiniai (tuneliai ir šachtos) bei šaltinėlis esantis rytiniame Pilies kalno šlaite („STRUCTUM“ Žurnalas sekmingam verslui 2014).

4. Nustatyta, kad sezoniskumas (gamtiniai procesai ar žmonių kiekio poveikis) sėdimams įtakos neturi.

5. Dėl kalno statinių deformacijų vystymosi būtina pratęsti jų geodezinį stebėjimą, ypač probleminėse vietose atlikti tvirtinimo darbus. Gedimino kalnas vertas nuolatinio specialistų dėmesio, nes tai yra Lietuvos valstybingumo ir šalies sostinės simboliu tapęs kultūros paveldo objektas, kuris per visą mūsų istoriją buvo vienas iš svarbiausių Vilniaus dominančių.

Padėkos

Dėkojame UAB „Inžineriniai tyrinėjimai“ buvusiam geodezininkui-specialistui R. Lučiūnui bei Geodezijos ir kadastro katedros darbuotojams už pateiktus duomenis, pasidalintą patirtį, suteiktą informaciją ir sugaištą laiką.

Literatūra

Akcinė bendrovė „Inžineriniai tyrinėjimai“ filialas „Inžinerinė geodezija“. 1995 – 2008 m. Gedimino kalno pastatų sėdimų stebėjimo techninės ataskaitos. Vilnius.

Gedimino kalnas: išgelbėtas ir nušvitęs. „STRUCTUM“

Žurnalas sekmingam verslui. Vilnius, 2014 m., 10–19 p.

Ražinskas, A.; Zakarevičius, A. 1979. Taikomoji geodezija. Vilnius: Mokslas, 326 p.

RESEARCHING OF VILNIUS UPPER CASTLE VERTICAL DEFORMATIONS

G. Miltinytė, V. Č. Aksamitauskas

Summary

The main objective of this work is to investigate vertical deformations on the Vilnius Upper Castle. Data from the measurement technical reports are being used to carry out the research. The monitoring works started in 1968 and lasted till 2008. The objects of the research are the Gediminas' Tower and a part of Southwestern Defensive Wall, Grand Duke Palace, Foundation of the Southern Tower, Northern Wall, Southern Retaining Wall, Eastern Retaining Wall and North-Western Retaining wall (next to the Gediminas' Tower). Review of all the measurement cycles carried out and findings presented. Collected systemized data is processed with mathematical–statistical methods. In order to investigate the state of the buildings, data is presented graphically. While analyzing the graphics, changes of the buildings were investigated and possible causes of their appearance are presented. To investigate climate impact to the volume of the sittings, hydro-meteorological data from the Hydro-meteorological Service under the Lithuanian Ministry of Environment was used.

Keywords: Vilnius Upper Castle, Gediminas' Tower, Grand Duke Palace, construction deformations, vertical deformations, cycle.

E PRIEDAS. Straipsnis 10-oje tarptautinėje konferencijoje
„Aplinkos inžinerija

Research of Vilnius Upper Castle vertical deformations

Mindaugas Markelionis¹, Greta Miltinytė², Darius Popovas³, Vladislovas Česlovas Aksamitauskas⁴

^{1,2,3,4}*Department of Geodesy and Cadastre, Vilnius Gediminas technical university, Vilnius, Lithuania*
E-mails: ¹mindaugas.markelionis@stud.vgtu.lt; ²greta.miltinyte@stud.vgtu.lt; ³darius.popovas@vgtu.lt;
⁴ceslovas.aksamitauskas@vgtu.lt

Abstract. The aims of this study were to review the monitoring methodology of the vertical deformations and to identify the reasons of deformations that occur in structures of Vilnius Upper Castle, Lithuania. Collected systemized data is processed with mathematical–statistical methods. In order to investigate the state of the buildings, a new cycle of measurements (XIV) was carried out in 2016. Data of all measurement cycles is presented and compared with previous data that was provided in technical reports of measurement cycles (first measurements began in 1968). In order to investigate conditions of the structures, data is presented graphically. When analyzing the graphics, it is possible to investigate changes of the buildings and possible causes of their appearance are presented. Long-term research and results have shown, that all the cracks and crevices that were found during monitoring (1968 to 2016) in Upper Castle’s structures were caused by large and uneven deformations.

Keywords: Vilnius Upper Castle, Gediminas’ Tower, Grand Duke Palace, construction deformations, vertical deformations, cycle.

Conference topic: Technologies of geodesy and cadastre.

Introduction

There are two types of deformations: vertical deformation and horizontal displacement of the soil (landslide). The most common causes of vertical deformation of buildings are: uneven structure of the geological ground under the building; the rise of the soil before installing the foundations; soil elevation (swelling) because of the cold, moisture and the warming of soil, weight of the building, alteration of the ground pressure during weight changes of the building, uneven pressure distribution depending on weight of the building under the foundations, dimensions of the foundations, hardness and shape, dynamic loads to the ground, variations of the strength of soil during underground constructions, influence of the human, working mechanisms etc. All the cracks and fractures are caused by large and uneven deformations. Geodetic techniques have traditionally been used mainly for determining the absolute displacements of selected points on the surface of the object with respect to some reference points that are assumed to be stable. Non-geodetic techniques have mainly been used for relative deformation measurements within the deformable object and its surroundings (Çelik et al., 2001; USACE, 2002). Each main measurement technique has its own advantages and drawbacks. Geodetic techniques, through a network of points interconnected by height, angle and/or distance measurements, usually supply a sufficient redundancy of observations for the statistical evaluation of their quality and for a detection of errors (Erol et al., 2004).

Vilnius Upper Castle is an important 16th – 19th centuries architectural, historical and archaeological monument that has a high national meaning. As it is necessary to save this object for the future generations, on the 6th of April 2016, a new (XIV) measurement cycle was completed in order to follow further conditions of the castle and to be able to predict future vertical deformations (Baselga et al., 2011). Measurements were carried out in accordance with leveling accuracy of second order, and the received data was compared with data of previous measurement cycles that was provided in technical reports (the first measurements began in 1968).

The main objective of this work is to investigate vertical deformations on the Vilnius Upper Castle.

Methodology of the research – collection and processing of the long-term monitoring data.

Sizes of vertical deformations obtained during measurements are compared with the previously set values. Research is carried out to determine the changes occurring in buildings and the reasons of vertical deformations to make a conclusion about the certainty of situation in the area (Henriques and Casaca, 2007).

Data from the technical reports of the long-term measurements that have been prepared for each cycle of measurements were used to implement this study. The monitoring works started in November 1968 and lasted until April 2008. During the 40-years period, XIII cycles of measurement were carried out. Measurements performed by Ltd. “Inžineriniai tyrinėjimai”. Developer of the measurements was Public Enterprise “Vilniaus pilių direkcija”. Vertical and horizontal deformations of Gediminas Hill and other structures were monitored during the measurements. During XIV cycle of measurements it is chosen to analyze vertical deformations of Vilnius Upper Castle structures.

The objects of the research are the Gediminas' Tower and a part of Southwestern Defensive Wall, Grand Duke Palace, Foundation of the Southern Tower, Northern Wall, Southern Retaining Wall, Eastern Retaining Wall and North-Western Retaining Wall (next to the Gediminas' Tower). During the cycle, it was decided to abandon monitoring of the Northern Wall deformations because of the negligible displacements of geodetic marks. It was also found, that using data from the technical reports of the long-term measurements, it is difficult to draw conclusions about the Northern Wall vertical deformations and tilting. Gediminas Upper Castle structure, geodetic marks of vertical deformations and levelling scheme are shown in figure 1.

Fig. 1. Monitoring of geodetic marks of vertical deformation and levelling scheme on the 6th of April, 2016.

Monitoring of vertical deformations was carried out according to the accuracy requirements of geometric levelling of second order. All other measurements were carried out trying to stay close to previous cycles principal schemes of geodetic marks levelling. The first monitoring cycles were based on initial deep bench-marks Num. 5656, Num. 5657, Num. 5658 and Num. 5660 (vertical deformation monitoring technical reports of Gediminas Hill structures from 1995 to 2008). Minor changes in the scheme occurred due to the merging of analogue measurement schemes into a common complex, additionally established and destroyed marks or new bench-marks. State standard GOST 24846 - 81 "Soil. Methods of strain measurement of buildings and equipment framework" and requirements as well as measurement methods from „Buildings and equipment foundations and framework strain forecasting manual“ (in force at the time) were used during the measurements. Measurements were carried out using automatic level NA 3003 and code rods of different length made by company "Leica". Visual FoxPro software was used to compensate levelling moves and calculate altitudes of marks.

Results

years since December 1995 the biggest average vertical deformation was detected on Southern Retaining Wall (21.8 mm) and the lowest – at Northern Wall (5.1 mm). Southern Retaining Wall's mark Num. 9455 vertical deformation during data of measurements was the biggest – 41.0 mm and the East Retaining Wall's mark Num. 19n/5207 contrariwise – 0.9 mm.

Comparing all data (from November 1968) with the data of the last cycle in 2016 (48-years period), most average vertical deformations were established at Grand Duke Palace (35.2 mm), Gediminas Tower and a part of Southwestern Defensive Wall (28.7 mm). Foundation of the Southern Tower has not been recorded due to the corrosion of marks. The biggest vertical deformation during period since 1968 was observed at Grand Duke's Palace mark Num. 5627 (73.3 mm); the lowest 8.1 mm of mark Num. 5630. Since December 1995 (21-years period) the biggest average vertical deformation was detected on Southern Retaining Wall (26.4 mm), the lowest – 10.6 mm of Southwestern Defensive Wall (near Gediminas Tower), the vertical deformation of East Defensive Wall on average was 17.7 mm. South Defensive Wall's vertical deformation value (48.7 mm) was established of the mark Num. 9270; the lowest - of the mark Num. 19n/5207 (East Defensive Wall) – 1.2 mm.

To investigate conditions of the structures, vertical deformation values are displayed graphically in figures 2 to 7. All the charts can be used to identify risk areas of cracks and the heel angle of the structure by a verticle. In order to examine changes of structures, sedentaries of Vilnius Upper Castle's structures are shown by the directions of the major axes. Vertical sedentaries of Gediminas Tower, a part of Southwestern Defensive Wall, Grand Duke Palace and foundations of Southern Tower (since 1968), can be seen sufficiently different in the charts when comparing the IV and III measurement cycles values. The differences are due to the fact that deep bench-mark (that previously was an itial deep bench-mark) was also affected by the vertical deformations and its deformation value was increased by 10.9 mm since 1968. For this reason, all the values of vertical deformations obtained in 1995 were adjusted. These values are considered to be final. All the charts were adjusted by the value changes in the IV measurement cycle.

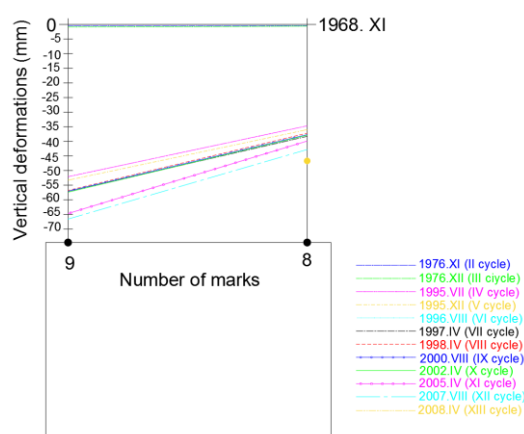


Fig. 2. Vertical deformations of foundations of Southern Tower.

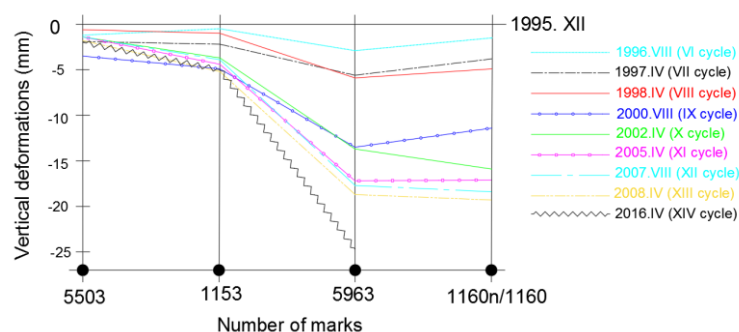


Fig. 3. Vertical deformations of Eastern Retaining Wall.

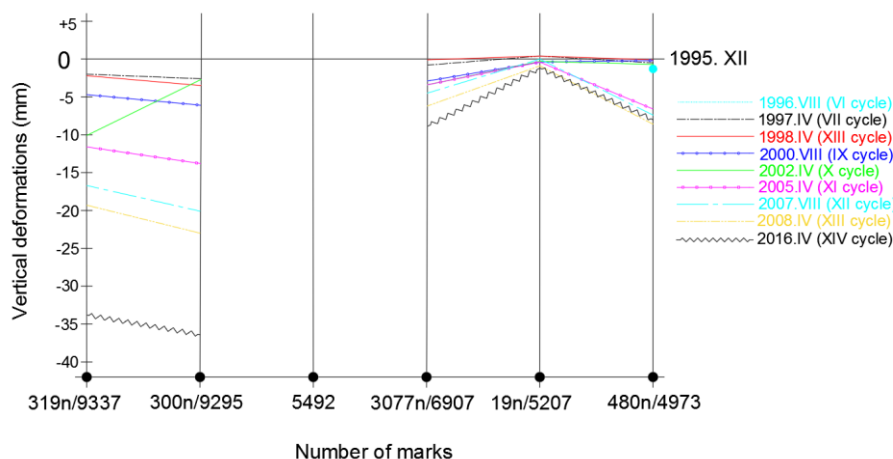


Fig. 4 Vertical deformations of Southern Retaining Wall.

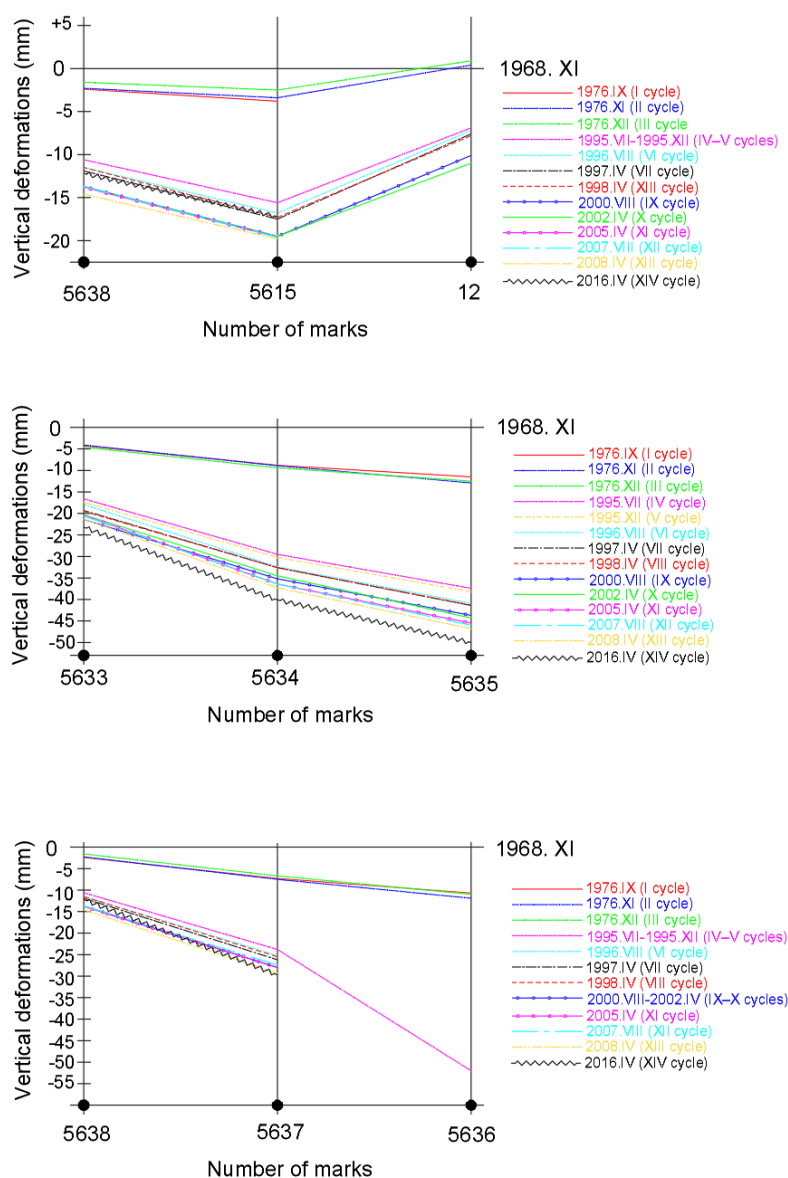


Fig. 5. Vertical deformations of Gedinimas Tower and a part of Southwestern Defensive Wall.

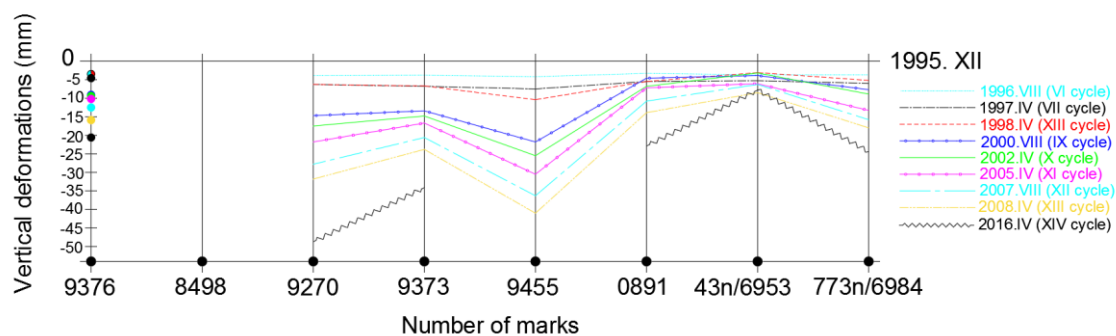


Fig. 6. Vertical deformations of Southern Defensive Wall.

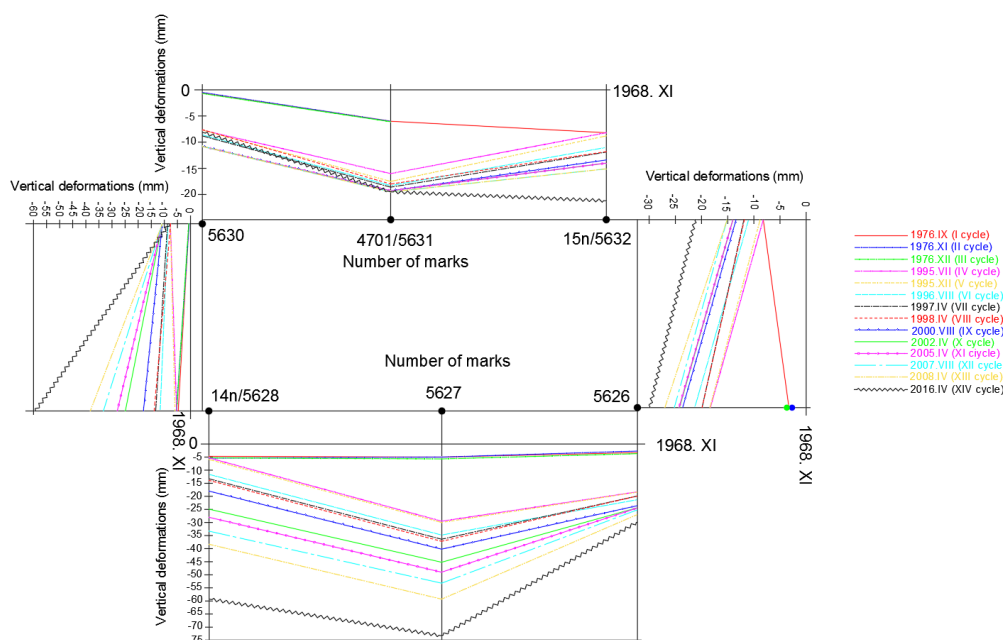


Fig. 7. Vertical deformations of Grand Duke Palace.

The whole area was inspected carefully and 26 marks have been found around the Upper Castle. One of the Gediminas Castle marks is shown in figure 8. Visible cracks in the structures (figure 8, on the right) confirm about permanent deformations.



Fig. 8. Mark Num. 5634 on the left; on the right – visible crack on Grand Duke Palace.

Causes of deformations

Deformations are caused by natural and technogenic processes. Natural factors are classified according to:

- uneven ground geological structure of the building;
- feature of soil compression and its horizontal displacement (landslides);
- soil elevation (swelling) because of the cold;
- impact of moisture and soil warming;
- hydro-meteorological conditions: temperature fluctuations (seasonal and long-term), changes in groundwater level and soil moisture.

Technogenic factors are classified according to:

- weight of structures;
- changes of soil properties due to the groundwater level change;

- changes in soil durability while constructing underground;
- influence of ongoing nearby constructions of buildings and structures;
- due to human influence: vibrations caused by working machines and other mechanism (Ražinskas, 1979).

Steep slopes, plants, rotting stumps are causing erosion and landslides of the slopes. Several large landslides were mentioned in technical reports (a new landslide was recorded at the end of 2016), which probably influenced vertical deformations of the Vilnius Upper Hill structures. Poor draining, improperly performed works of slope stabilization, trample down vegetation areas, existing underground structures (tunnels and shafts). In the article of “STRUCTUM” magazine (Lekaviciene, 2014), it was offered to analyse all previously collected information of Vilnius Upper Castle conditions when the threat has occurred. The article also reveals one of the secrets of Gediminas Hill – underground tunnels: mysteriously winding underground corridors entering premises, brick or wood lumber walls, in some places ceilings have wooden supports. Scheme of the tunnels and photos are shown in Figure 9. According to the head of the Public Enterprise “Lietuvos paminklai“ V. Drumsta, underground tunnels were dug by prisoners of war during WW II. Condition of these tunnels is not investigated yet, but the fact is that effect exists. It is because of bad conditions of the overall underground structures. While searching for causes of failures and landslides of the hill, scientists raised hypothesis that the main issue is poor conditions of underground structures and failure of constructions (Lekaviciene, 2014).

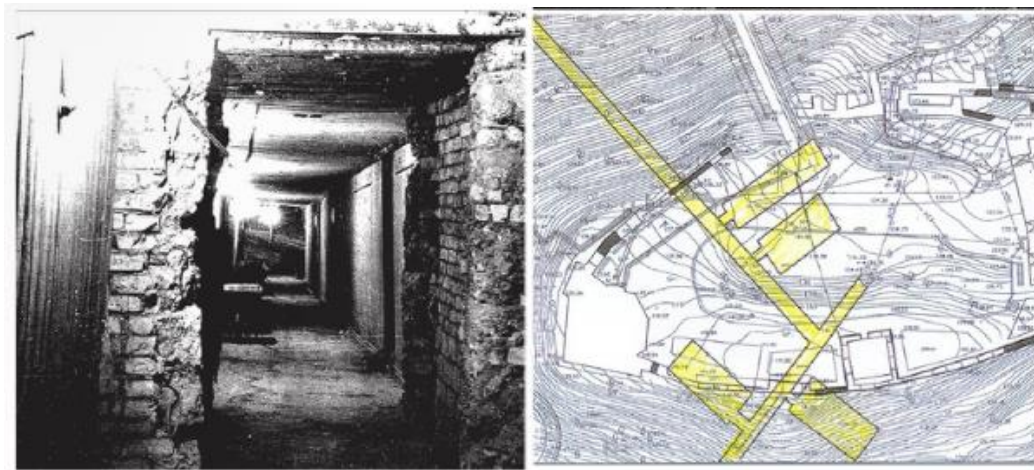


Fig. 9. Underground tunnels of Gediminas Hill (Lekaviciene, 2014).

The most problematic area of Gediminas Hill is a wellspring on the eastern slope of the Castle Hill. This area is on top of the hill between bricks of the defensive wall. It is a former water artery of well which opened after landslide. Earlier, this water artery was vitally important for Castle hill defenders but nowadays this may be the cause of the slope erosion.

Another problem causing hills deformations is rain water collection and drainage. It was found that drainage pipes are worn out, cracked and have moved from their places. Some of them are not connected. For this reason, water leaks and erosion of the soil starts (Lekaviciene, 2014).

Deformations of structures might have also been influenced by human activities. Lithuanian Grand Duke Palace restoration works that were started in 2002 may be classified as such activity. Also, in 2003, pedestrian and cargo lift was installed on the northern slope. Vibrations caused by the installation of pedestrian and cargo lift, may also have an impact on stability of the slope. All these reasons can influence results of measurements since the cycle (X) was started in 2002.

Conclusions

1. Longterm research (1968 – 2016) of cracks in the buildings of the Upper Castle have shown that all the features of the castle have been deformed during the time of the measurements (deformations and cracks in the walls have occurred);

2. Investigations suggest that the biggest vertical deformation was seen at Southeastern side of the hill. Since November 1968 (durring 48 years), on average, the biggest vertical deformation of structures has happened in foundation of the Grand Duke Palace (35.2 mm); since December 1995 (durring 21 years) – on Southern Retaining Wall (26.4 mm). The least vertical deformation was detected on north-west side of the hill. The lowest vertical deformation since November 1968 (durring 48 years) was established at Gediminas Tower and a part of

Southwestern Retaining Wall (28.7 mm); since December 1995 (during 21 year) – on Southwestern Defensive Wall (near Gediminas Tower) (10.6 mm);

3. The vertical deformation values depend on many factors: geological, hydrogeological and hydrometeorological conditions, human economic activity, structural stability of buildings. Steep slopes, plants, rotting stumps are causing the slopes erosion and landslides. Poor draining, improperly performed works of slope stabilization, trample down vegetation areas, existing underground structures (tunnels and shafts), vibrations of pedestrian and cargo lift, restoration works of Grand Duke Palace and former water artery on the eastern side of Castle Hill also have a significant impact;

4. The vertical deformation values were within the limits of the accuracy of measurements;

5. In order to avoid vertical deformations, it is necessary to extend geodetic monitoring, especially in problem areas and carry out reinforcement works. Gediminas Hill is worthy to be monitored by specialists as it is Lithuanian statehood and became the symbol of the cultural heritage of the country's capital, which is the most important dominant object throughout the history of Vilnius city.

Acknowledgements

Authors thank "Inžineriniai tyrinėjimai" former surveyor-specialist R. Lučiūnas and Department of Geodesy and Cadastre staff for the information, instruments, experience and time spent.

References

- Corporation „Inžineriniai tyrinėjimai“ branch „Inžinerinė geodezija“. 1995 – 2008 m. Gedimino kalno pastatų sėdimų stebėjimo techninės ataskaitos. Vilnius;
- Lekaviciene, E. 2014. Gedimino kalnas: išgelbėtas ir nušvitęs. „STRUCTUM“ Žurnalas sekmingam verslui. Vilnius, 2014 m., 10–19 p.;
- Baselga S., Garrigues P., Berné J. L., Anquela A. B., and Martín A., 2011. Deformation Monitoring in Historic Buildings: A Case Study. Survey Review Vol.43, p. Pages 484-492;
- Çelik, R. N., Ayan, T., Denli, H., Özlüdemir, T., Erol, S., Özöner, B., Apaydın, N., Erincer, M., Leinen, S., Groten, E., 2001. Monitoring Deformation on Karasu Viaduct Using GPS and Precise Levelling Techniques, Kluwer Academic Publisher, Netherlands
- Erol, S., Erol, B., & Ayan, T., 2004. A general review of the deformation monitoring techniques and a case study: analysing deformations using GPS/levelling. In XXth ISPRS Congress (pp. 12-23). USACE, (2002): Engineering & Design – Structural Deformation Surveying. United states Army Corps of Engineers manual, Department of the Army, Washington DC. No. 1110-2-1009, Pp 2-5 to 2-6;
- Henriques, M. J., Casaca, J., 2007. Monitoring vertical displacements by means of geometric levelling – Historical Constructions, Guimaraes-Portugal.

